

Foil heating and cooling; injection beam absorber (ACD)

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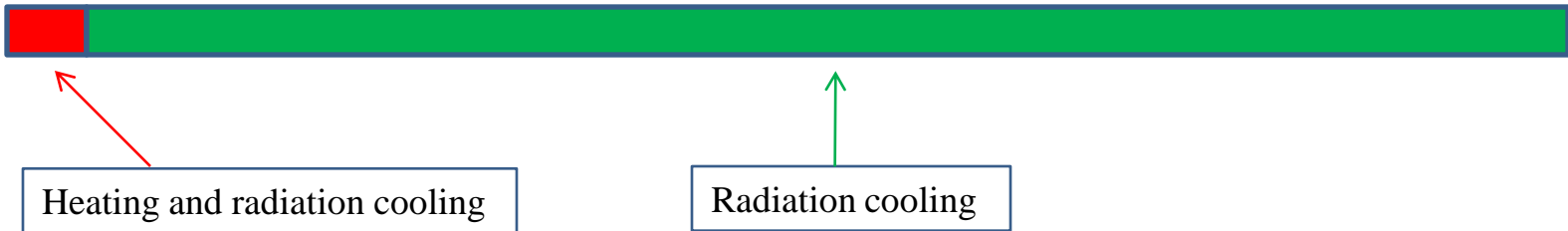
Fermilab

*Project X Collaboration Meeting,
September 11-12, 2009*

Foil heating and cooling

0 4.3 ms

100 ms

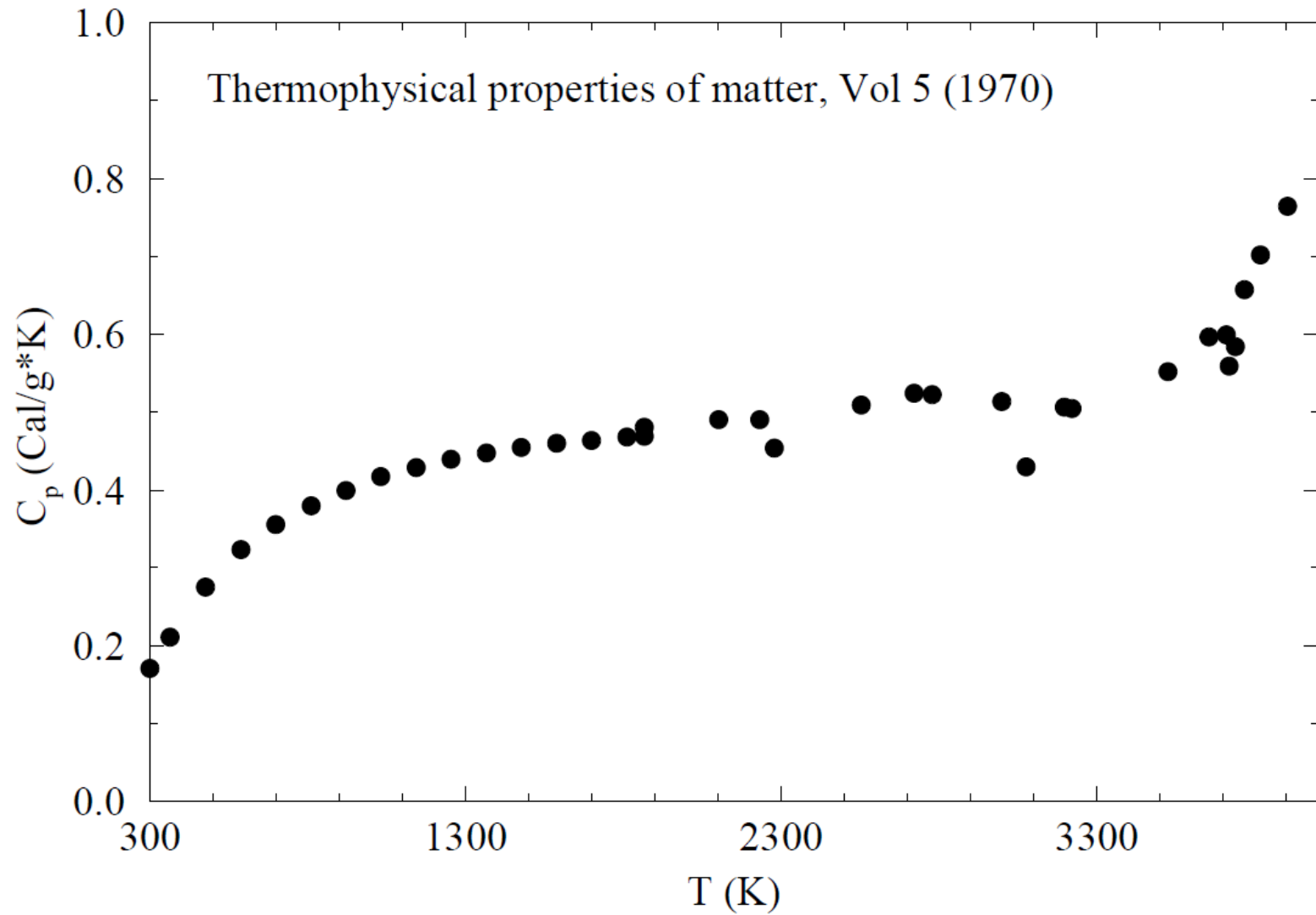


- Thermal analysis is performed for a single cycle (4.284 msec) with subsequent **radiation cooling** until next cycle.
- The hottest spot with linear dimension ≈ 0.3 mm (codes STRUCT/ORBIT)
- Heat *conduction* in the foil is *ignored* (ANSYS is not used)
- $2.67\text{E}13$ proton/cycle @ 10 Hz \rightarrow **2.67E14 proton/sec**

$$\frac{\partial T}{\partial t} = \frac{N}{\rho c_p} \left| \frac{dE}{dz} \right| - \frac{\epsilon \sigma_{SB}}{\Delta z \rho c_p} (T^4 - T_0^4) \quad 0 \leq t \leq \tau_p$$

$$\frac{\partial T}{\partial t} = - \frac{\epsilon \sigma_{SB}}{\Delta z \rho c_p} (T^4 - T_0^4) \quad \tau_p \leq t \leq \tau$$

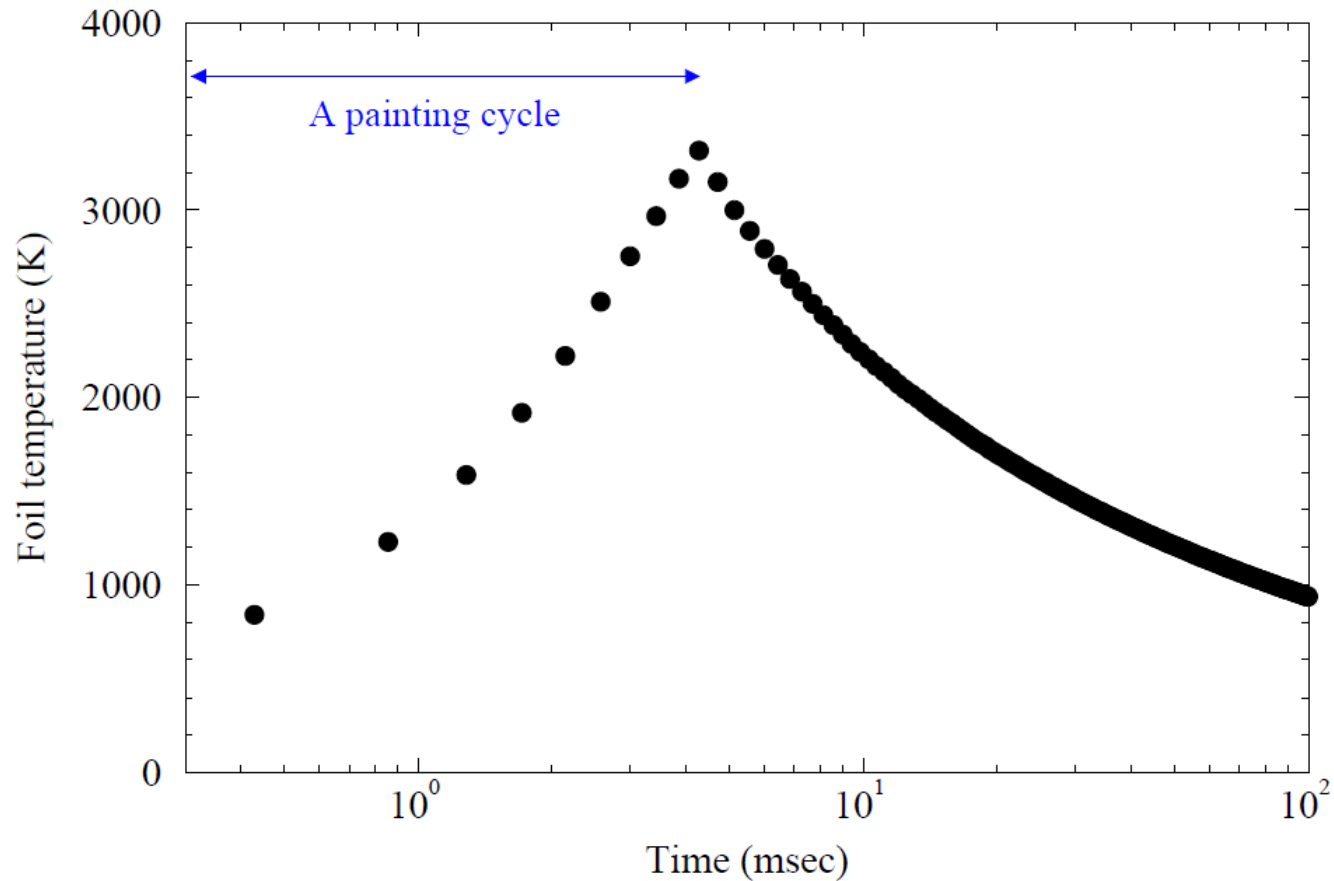
Measured dependence of specific heat, c_p , on T (graphite)



Foil heating and cooling

- Valeri Lebedev suggested taking into account that a fraction of generated **δ -electrons** will escape the foil thus reducing the amount of deposited energy. And the foil can be rotated by, e.g. 45 degrees, relative to the beam → extra reduction factor of 1.4 due to increased area of the hottest spot.
- Detailed calculation of the fraction was performed with **MCNPX 2.6** code. It allows us to track electrons (and secondary photons) down to **1 keV**. (Range of 1-keV electrons is approximately 1% of the foil thickness.) In this calculation uniform spatial distribution of generated **δ -electrons** was used. Realistic energy and angular distributions were employed.
- According to **MCNPX 2.6**, **23%** of energy deposited in the 600- $\mu\text{g}/\text{cm}^2$ carbon foil by 2-GeV protons due to ionization (dE/dx) will be taken away by the **δ -electrons**. That is, **77%** of the initially deposited energy will give rise to the foil heating.

Foil temperature without rotation

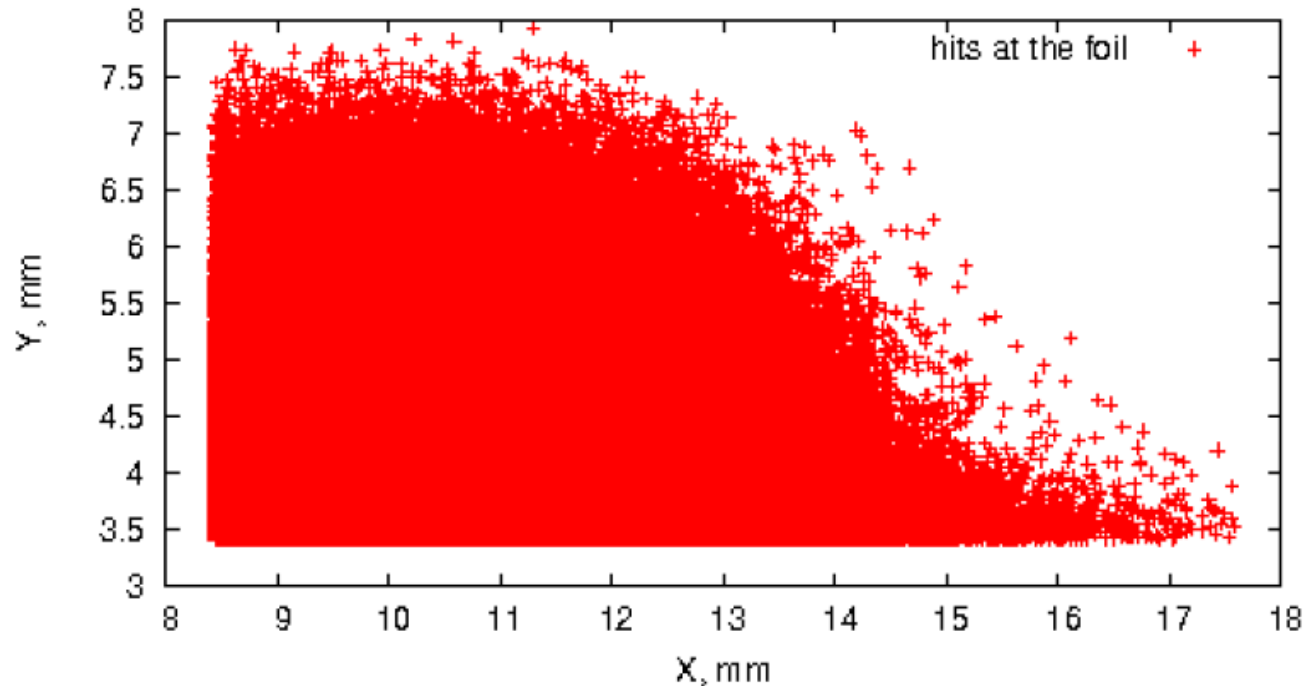


Foil rotation $\rightarrow T_{\max} / 1.4 = 3320 / 1.4 \approx 2350 \text{ K} \rightarrow$ **ANSYS can help**

Injection beam absorber

- Calculations with **STRUCT** and **MARS** codes
- Surface water activation
- Power density in magnet coils
- Residual activity

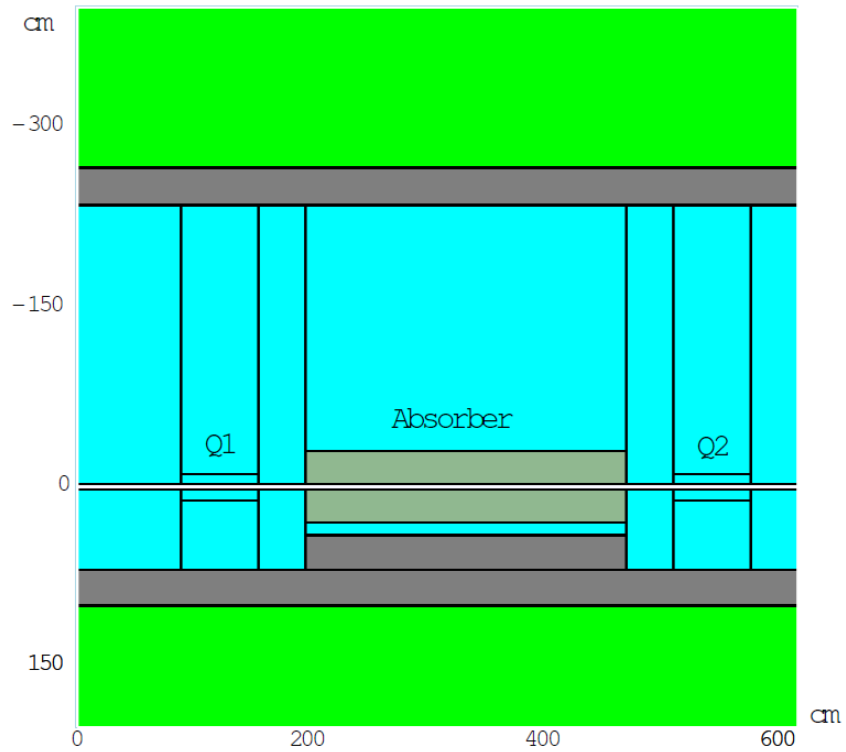
Example of STRUCT output which serves as an input to MARS code



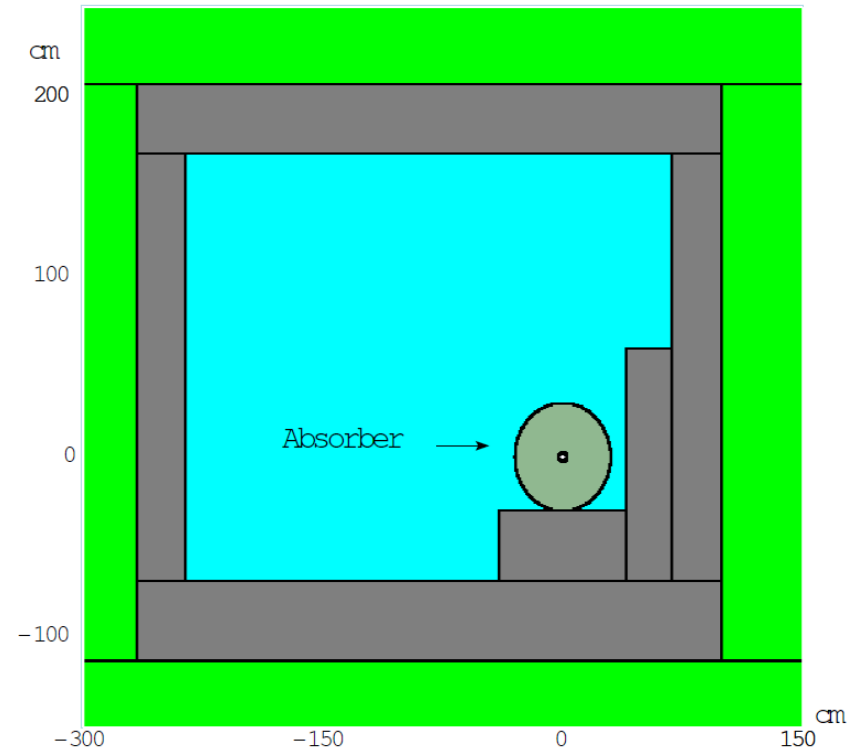
- 2% of H^- miss the foil $\rightarrow Q_1$
- 1% of $H^0 \rightarrow$ absorber

Geometry

Plan view

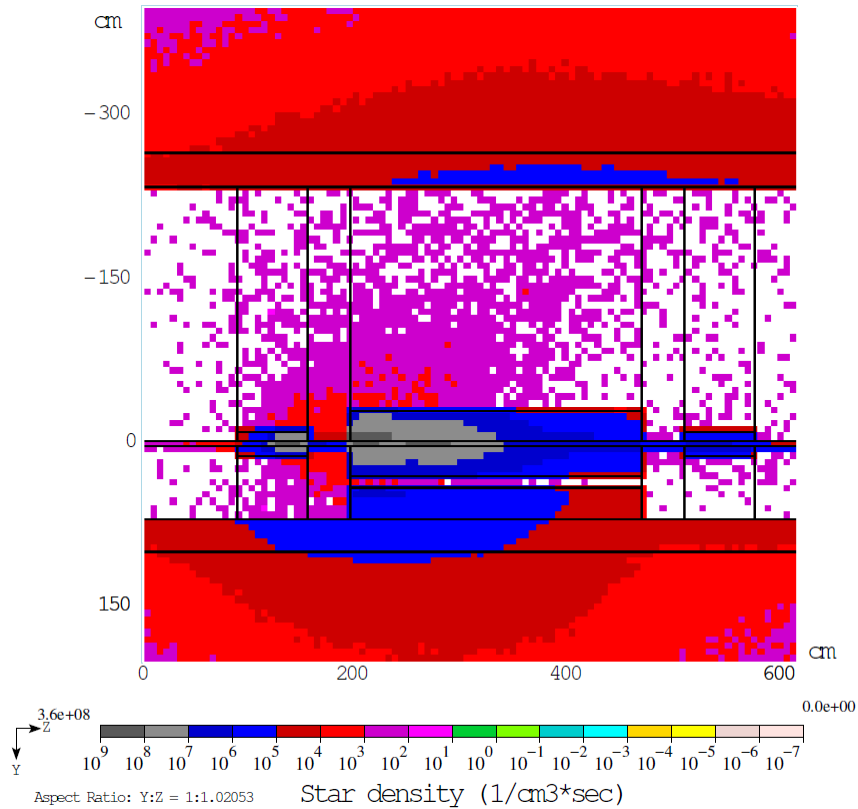


Cross section

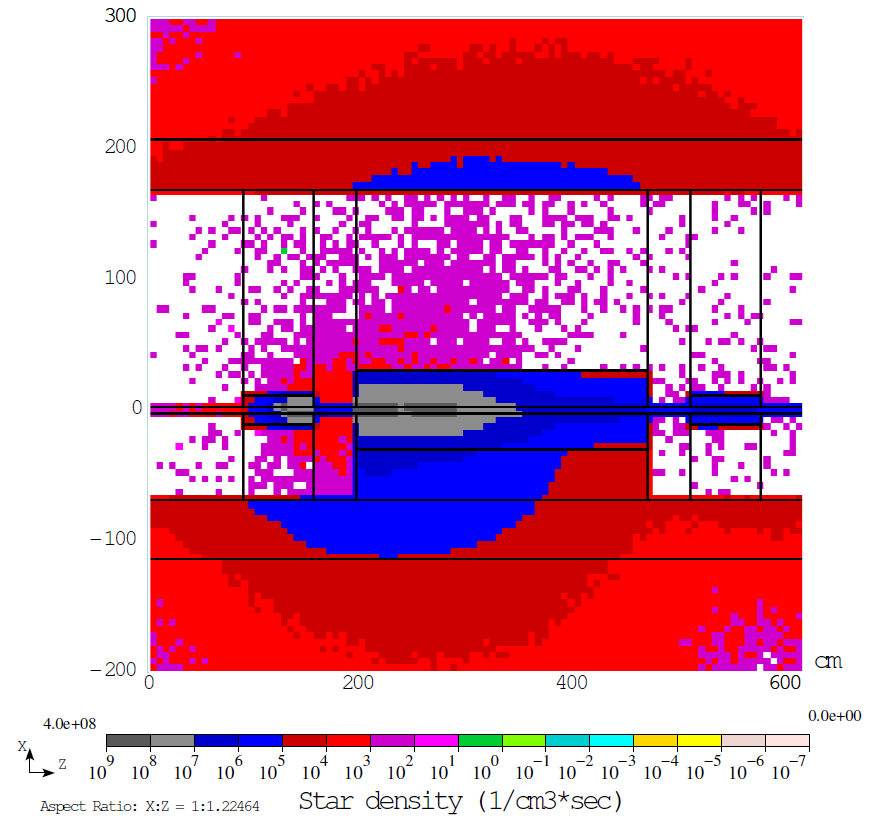


Calculated star density distributions

Plan view



Elevation view



Surface water activation (using sump pumps)

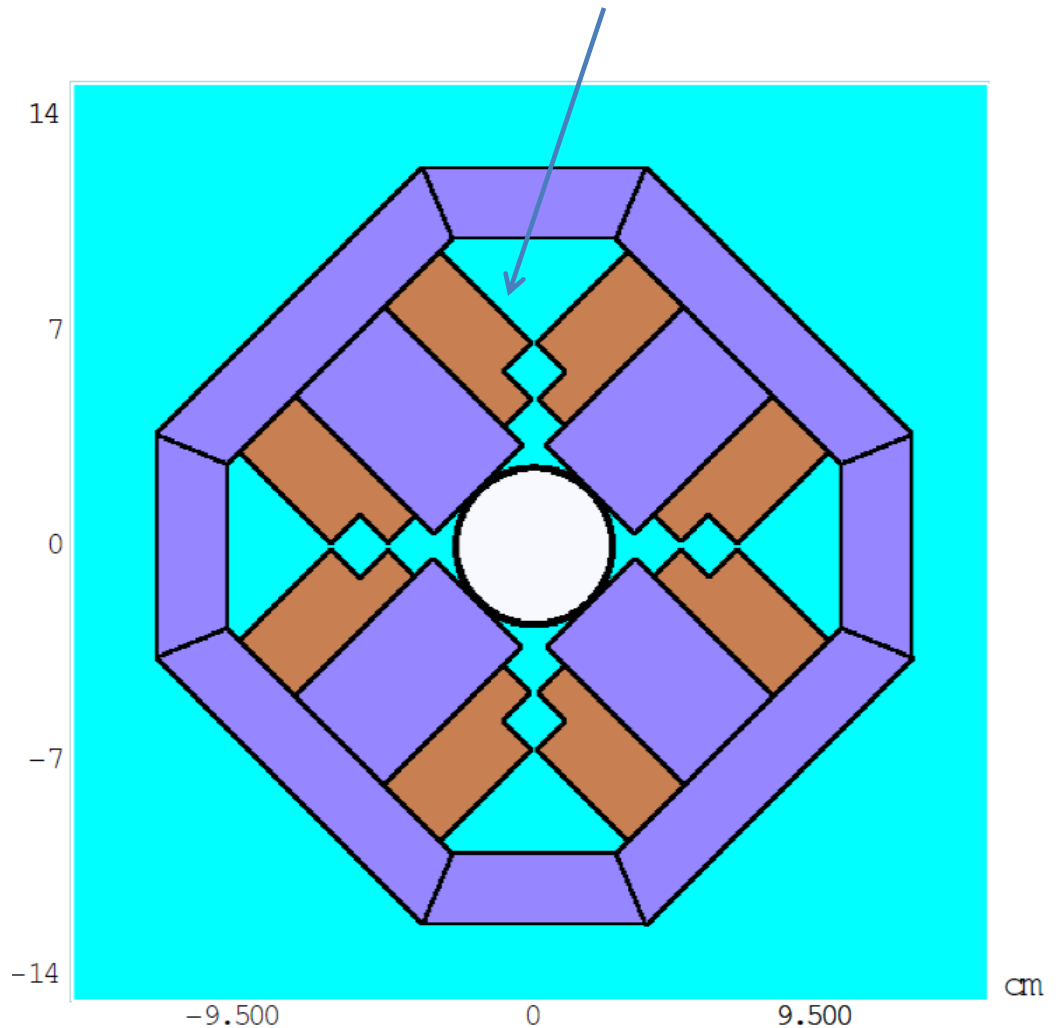
- **Groundwater** activation takes more time and requires analysis of geological structures (K. Vaziri).
- For this beam absorber (30 cm thick iron surrounded with 30-cm bricks of concrete) the calculated $S_{\max} \approx 1.55\text{E}5 \text{ star/cm}^3\cdot\text{sec}$
- According to Concentration Model it means the surface water gets activated to the permitted max in about **4 months** → removal of activated water 3 times a year. **Common practice is to do that once a year.**
- The absorber and shielding can be optimized to reduce the rate of surface water activation.

Absorbed dose in magnet coils

Usually **epoxy** can survive
absorbed dose up to
400 Mrad = 4 MGy

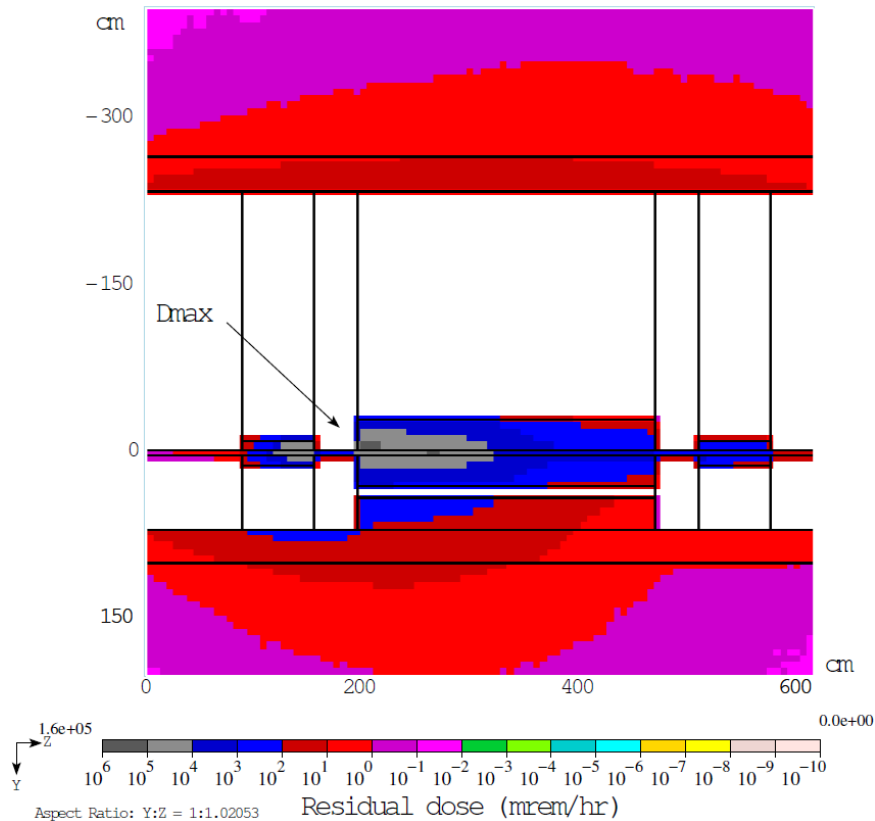
Q1 \rightarrow 4.8 MGy/yr $\rightarrow \approx$ **1 yr**

Q2 \rightarrow 0.4 MGy/yr \rightarrow **10 yrs**

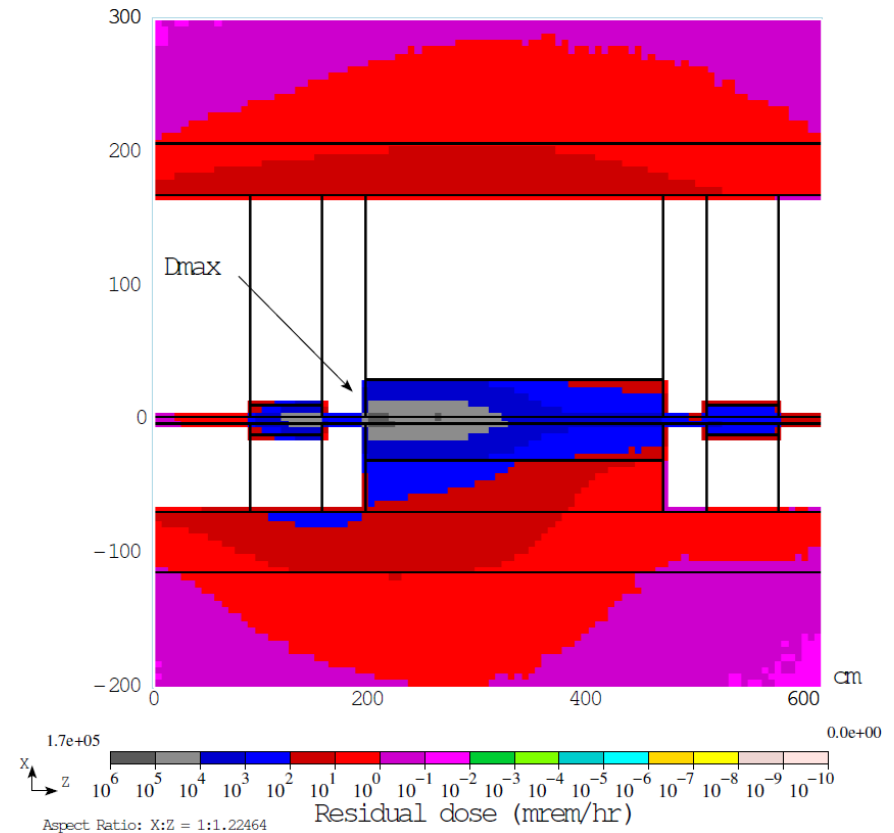


Residual dose (it is good to have it ≈ 100 mrem/hr)

Plan view



Elevation view



Conclusions

- Foil heating without taking into account heat conduction is too high (≈ 2350 K). **ANSYS** calculations should provide more realistic data.
- Surface water activation can be reduced by means of absorber/shielding optimization. **Removal of activated water can be required twice or once a year.**
- The problem of activation of beam line components (mostly absorber) can be mitigated with **extra marble shielding** applied to the absorber.
- **Survival of the quad immediately downstream the foil looks like the major show-stopper.** The epoxy in the quad coils will survive for about **a year**.